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Creation of neutral disks during outbursts of symbiotic binaries

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Abstract. Multiwavelength modelling of the spectral energy distribution of symbiotic binaries suggests that a neutral disk-like zone is created around the hot star near the orbital plane during active phases. Presumably, this is connected with the enhanced wind from the active hot star. To test this idea, we applied the wind compression model to active hot stars in symbiotic binaries, within which the wind particles are compressed more to the equatorial plane due to a fast rotation of the hot star. Accordingly, we calculated the ionization structure for such compressed wind and ionizing photons from the hot star. We found that the hot star wind, enhanced during active phases to $\sim (10^{-7} - 10^{-6}) M_{\odot} \text{yr}^{-1}$, and the rotational velocity of $100 - 350 \text{ km s}^{-1}$ at the star's equator lead to formation of a neutral disk-shaped zone. The presence of such disks is transient, being connected with the active phases of symbiotic binaries. During quiescent phases, such neutral disks cannot be created, because of insufficient mass loss rate.

1. Introduction

Symbiotic stars are long-period interacting binary systems, which comprise a late-type giant and a hot compact star, which is in most cases a white dwarf (WD). Accretion from the giant's wind makes the WD to be a strong source of ionizing radiation. During so-called quiescent phases, it ionizes a fraction of the giant's wind giving rise to a dense nebula extended within the binary (Seaquist, Taylor, & Button 1984). The temperature of the hot star is $T_h \sim 10^5 \text{ K}$ during quiescence. However, during active phases, the ionization structure changes drastically. In symbiotic binaries with high orbital inclination we observe a two-temperature-type of the UV spectrum. The cooler component is produced by a relatively warm stellar source ($T_h \sim 22\,000 \text{ K}$), while the hotter one is represented by the highly ionized emission lines and a strong nebular continuum. This situation suggests the presence of a neutral disk-like structured material surrounding the accretor and hot emitting regions located above/below the disk, which is seen approximately edge-on (see Fig. 27 of Skopal 2005). A rapid creation of such ionization structure during the first days/weeks of outbursts is connected with the enhanced hot star wind. During quiescence the mass loss rate from the hot star is $10^{-8} M_{\odot} \text{yr}^{-1}$, but in activity it increases to $\sim (10^{-7} - 10^{-6}) M_{\odot} \text{yr}^{-1}$ (Skopal 2006). The wind gives rise to the optical bursts by reprocessing high-energy photons from the Lyman continuum to the optical/UV (Skopal et al. 2009).

The rotation of the hot star with radiation driven wind leads to compression of the outflowing material towards equatorial regions due to conservation of the angular momentum. This wind compression model was developed by Bjorkman & Cassinelli

(1993). If the streamlines of gas from both hemispheres do not cross the equator then we are talking about the wind compressed zone (WCZ) model described by Ignace et al. (1996). In this contribution, we test the idea if the compression of the enhanced wind from the rotating hot star towards the equatorial regions could create such neutral disk-like structure around the hot star in symbiotic binaries during their active phases, and thus to simulate the above-mentioned hot object structure based on modelling SED.

2. Density in the wind compression model

Density in the hot star wind as a function of polar coordinates (r, θ) follows from mass continuity equation

$$N_H(r, \theta) = \frac{\dot{M}}{4\pi r^2 \mu_m m_H v_r(r)} \left(\frac{d\mu}{d\mu_0} \right)^{-1}, \quad (1)$$

where the compression of the wind is described by the geometrical factor $d\mu/d\mu_0$ which depends on the parameters of the wind as well as on the rotational velocity of the hot star, \dot{M} is the mass loss rate of the active hot star, μ is the mean molecular weight and m_H is the mass of the hydrogen atom. For the radial component of the wind velocity $v_r(r)$ we adopted β -law

$$v_r(r) = v_\infty \left(1 - \frac{bR_*}{r} \right)^\beta, \quad (2)$$

where

$$b = 1 - \left(\frac{a}{v_\infty} \right)^{\frac{1}{\beta}}, \quad (3)$$

where a , v_∞ are the initial and terminal velocity of the wind, respectively and R_* is the radius of the hot star. More details about the wind compression model can be found in Lamers & Cassinelli (1999).

3. Ionization structure in the wind

Here we investigate the case, when the hot star is the source of both the ionizing photons and the wind particles. The ionization boundary is defined by the locus of points at which ionizing photons are completely consumed along path outward from the ionizing star. We calculated the ionization boundary by the equation of photoionization equilibrium which equals the number of ionizations with the number of recombinations. We assumed optically thick case (so called "Case B" or "on-the-spot approximation"). For the sake of simplicity, we assumed that wind contains only hydrogen atoms. Further we define the distance from the center of the hot star in units of its radius R_* , i.e. $r \rightarrow u = r/R_*$. For calculating ionization boundary in the hot star wind we derived an equation, which can formally be written as

$$X = f(u, \theta, a, v_\infty, \beta, v_{\text{rot}}), \quad (4)$$

where u , θ are polar coordinates ($\theta = 0$ at the rotational axis), a , v_∞ , β are parameters of the wind, v_{rot} is the rotational velocity of the hot star, and the value of the parameter X is given by

$$X = \frac{8\pi\mu_m^2 m_H^2}{\alpha_B} R_* L_H \left(\frac{v_\infty}{\dot{M}} \right)^2, \quad (5)$$

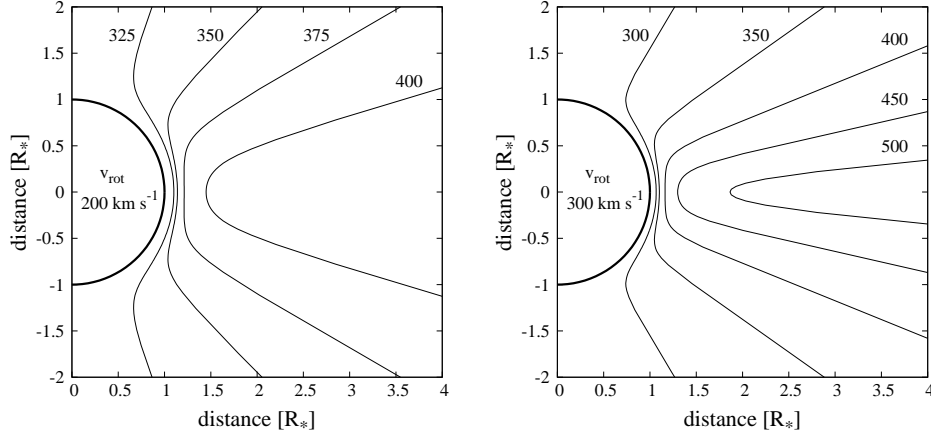


Figure 1. Examples of ionization boundaries in the wind for two different rotational velocities of the central hot star. Left: $v_{\text{rot}} = 200 \text{ km s}^{-1}$. Right: $v_{\text{rot}} = 300 \text{ km s}^{-1}$. Individual ionization boundaries are labeled by the value of the parameter X . From an ionization boundary towards the pole of the star (y -axis) there is the ionized zone, and towards the equatorial plane ($y = 0$) there is the neutral zone. Ionization structures are axially symmetric with respect to the polar (rotational) axis of the hot star. Distances are in units of radius of the active hot star R_* .

where L_H is the rate of photons from the hot star, capable of ionizing hydrogen (it is given by the temperature T_h and luminosity L_h of the ionizing source) and α_B is the total hydrogenic recombination coefficient in case B. To achieve complete ionization boundary in the hot star wind one has to solve Eq. (4) for each direction θ separately.

Most of the parameters of the active hot star and its wind in Eqs. (4) and (5) can be determined from observations. However the rotational velocity of the hot star in symbiotic binaries, required for Eq. (4), is not commonly known. Lower limit is given by the rotational velocities of the isolated white dwarfs and upper limit is given by the condition of the considered WCZ model, i.e. streamlines of gas do not cross the equator. We found to be the most appropriate to calculate models for different rotational velocities from 100 to 350 km s^{-1} .

In Fig. 1 we show some examples of ionization boundaries for different values of the parameter X resulting in creation of a neutral disk-like zone. We illustrate this case for two different rotational velocities of the central hot star, 200 and 300 km s^{-1} , respectively.

4. Discussion

We revealed that there is only a certain range of values of the parameter X , for which the neutral disk-like structure can be created near to the equatorial plane of the active hot star. For higher rotational velocities of the hot star (i.e. higher compression of the hot star wind towards the equatorial plane) this range is wider. For a given rotational velocity, small values of the parameter X (~ 200) correspond to ionization boundaries, which are enclosed at a vicinity of the hot star. On the other hand, increasing value of

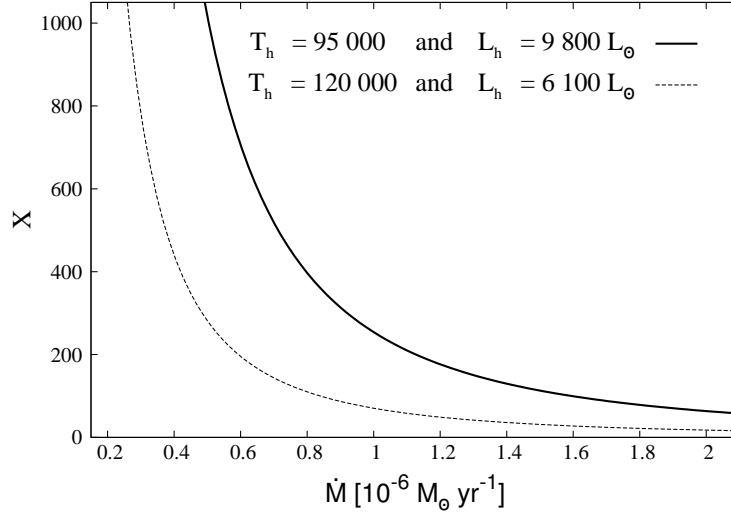


Figure 2. The value of the parameter X as a function of the mass loss rate from the hot star \dot{M} for two different combinations of the temperature T_h and luminosity L_h of the active hot star as the ionizing source.

X corresponds to moving the ionization boundary away from the vicinity of the active hot star, as well as to decreasing the opening angle of the neutral disk-like zone until it disappears for very high values of X . However, particular values depend also on the parameters of the active hot star wind.

Our calculations (e.g. Fig. 1) showed that creation of the neutral disk-like structure requires the value of the parameter X to be of the order of hundreds. Figure 2 shows the dependence of the parameter X on the mass loss rate from the hot star, \dot{M} . We calculated these dependences for observed parameters of the hot star and its wind, where we used two different combinations of its temperature T_h and luminosity L_h , which were taken from Sokoloski et al. (2006). From Fig. 2 we can see that observed mass loss rates from the active hot star, i.e. $\sim (10^{-7} - 10^{-6}) M_{\odot} \text{yr}^{-1}$, correspond to the required values of the parameter X .

According to Eq. (5), the parameter X strongly depends on the mass loss rate of the hot star \dot{M} as

$$X \propto \frac{1}{\dot{M}^2}. \quad (6)$$

The mass loss rate of the hot star during quiescent phases is by 1 - 2 orders lower than during active phases, which enlarges the parameter X so high that no neutral disk-like structure can be created during quiescence.

5. Conclusion

On the basis of the multiwavelength modelling of the spectral energy distribution of symbiotic binaries, Skopal (2005) suggested that neutral disk-like zone is created around the hot star near the orbital plane during active phases. Modelling the broad $H\alpha$ wings from the optically thin wind of the hot star showed enhancement of its stellar wind

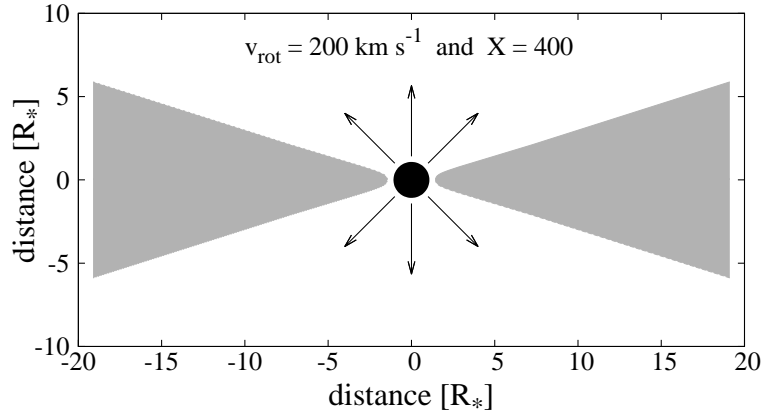


Figure 3. An example of ionization structure around the active hot star calculated for $v_{\text{rot}} = 200 \text{ km s}^{-1}$ and $X = 400$ ($\dot{M} \sim 6 \times 10^{-7} \text{ M}_{\odot} \text{ yr}^{-1}$), which is similar to the schematic one proposed on the basis of multiwavelength modelling of the spectral energy distribution of symbiotic stars (see Fig. 27 in Skopal 2005). White dwarf is denoted by the black filled circle and modelled neutral disk-like structure is grey. Material in the regions above and below this structure is ionized. Distances are in units of the radius of the central hot star R_* .

by a factor of ≥ 10 in activity (Skopal 2006). We found that the compression of the enhanced stellar wind in active phases from the rotating hot star towards equatorial regions can lead to the creation of the neutral disk-like structure around the active hot star. Figure 3 shows an example of ionization structure around the active hot star in symbiotic binaries calculated for $v_{\text{rot}} = 200 \text{ km s}^{-1}$ and $X = 400$ ($\dot{M} \sim 6 \times 10^{-7} \text{ M}_{\odot} \text{ yr}^{-1}$). Its shape is very similar to that shown in the schematic figure proposed by Skopal (2005). Finally, we explained that due to a low mass loss rate from the hot star, no neutral disk-like structure can be created during quiescent phases.

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